SAMPLING SYSTEM FOR FLUIDIZED BED APPLICATIONS -
RESULTS OF FOUR YEARS OF TESTING ON B&W/EPRI's 6' x 6' FLUIDIZED BED TEST FACILITY

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INTRODUCTION

In cooperation with The Electric Power Research Institute (EPRI), The Babcock & Wilcox Company (B&W) has built and is operating a 6-foot x 6-foot (6' x 6') Atmospheric Fluidized Bed Combustion (AFBC) Development Facility at its Alliance Research Center in Alliance, Ohio. A complete description of the facility design details is contained in EPRI Final Report CS-1688. An artist's rendition (Figure 1) identifies the major components of the facility.

The 6' x 6' size was selected as being large enough to bridge the gap between bench-scale units then in operation and larger, future units in the proposal and/or construction stages. The facility design is flexible (versatile to modifications) in many areas -- number of feed points, immersed tube bundle configurations, ash recycle configurations, interchangeable gas sample systems, etc. -- and is highly instrumented (controls, interlocks, data acquisition, and sampling) to closely simulate utility boiler designs. The size, design, and equipment selections have produced a hot test facility with the capability of generating significant performance data over extended periods of steady operation for a multiple number of planned test conditions.

The facility construction was completed in October 1977. Following a 5-month startup and debugging phase, the first test series was conducted in April 1978. Since that time, approximately 2000 hours of testing (five to eight test series) per year have been logged.

GAS SAMPLING SYSTEMS

Evaluation of the performance of the 6' x 6' AFBC test facility mandated accurate sampling and gas concentration measurements. For example, measurements of CO_2, CO, and Hydrocarbons are used in calculating combustion efficiency while the measurement of SO_2 is needed to calculate sulfur capture. Oxygen measurements, also used in performance calculations, are used by the operators in setting the desired facility operating test conditions. Figure 2 shows the location of the main gas and solids sample points on the 6' x 6' unit.

Obtaining gas concentration data required the use of a sampling system that included the use of many special instruments and/or equipment. The original system layout and details are shown on Figure 3 and Table 1, respectively. The two independent systems that make up the complete system are identified as the mobile and furnace outlet systems. Sampling flexibility is gained by being able to interchange systems and/or components. The original system has been expanded to include NO_x and Hydrocarbon measurements at the furnace outlet and CO_2 measurement at in-bed and freeboard locations.

Table 1

Tabulation of Gas Sampling System Details

Tank Farm Calibration Gases	SO_2, CO, O_2, NO, CO_2, Air, and N_2	
Instrument Air System	60 - 100 psig (2 - 3 SCFM)	
GAS SAMPLE SYSTEMS	**Furnace Outlet Probe**	**Mobile Probe**
SO_2, CO, O_2, NO_x, and CO_2 Analyzers	Yes	Yes
Hydrocarbon Analyzer	Yes	No
Common Tank Farm	Yes	Yes
Common Instrument Air Supply	Yes	Yes
Separate Sample Probes	Yes	Yes
Separate Filter-Cyclone Assemblies	Yes	Yes
Separate Heated Sample Lines	Yes	Yes
Separate Filter-Pump Systems	Yes	Yes
Instrument Air to Pump Control Switch	10 psig @ 1200 cc/minute	10 psig @ 1200 cc/minute
Cooling Water to Probes	20 gph maximum	20 gph maximum
GAS SAMPLING SOURCE	**Stack (Furnace Out)**	**"In-Bed" and Freeboard**
Approximate Source Gas Temperature	900°F	1650°F
Sample Gas Temperature @ Probe Discharge	310°F	310°F
Sample Gas Temperature in Sample Line	300°F	300°F
Sample Gas Temperature @ Pump Inlet	180°F	180°F
Sample Gas Temperature After Analyzers	Ambient (80°F)	Ambient (80°F)
Sample Gas Flow From Source	5 liters/minute	5 liters/minute
Sample Gas to O_2 Analyzers	250 cc/minute	250 cc/minute
Instrument Air to O_2 Analyzers	10 psig	10 psig
Sample Gas to SO_2, CO, and CO_2 Analyzers	1000 cc/minute	1000 cc/minute
Sample Gas to NO_x Analyzers	1200 cc/minute	1200 cc/minute
Instrument Air to NO_x Analyzers	35 psig	35 psig
Recorder "A" Gas Printout	SO_2, CO, O_2, and CO_2	
Recorder "B" Gas Printout		SO_2, CO, O_2, and NO_x

GAS SAMPLING WITH ORIGINAL PROBE-FILTER ASSEMBLIES

Furnace Outlet Gas Sample Location

The gas analysis from the furnace outlet is used in performance calculations and additionally to set and control the facility test conditions. This system must operate on a continuous basis. Figures 4 and 5, respectively, show the probe installation in the furnace outlet duct and the original probe-filter assembly. The water-cooled probe has an open-ended, concentric quartz tube for sample flow. In turn, the tube is connected to an in-line particulate filter assembly (glass cyclone collector/drop out bottle and frit-fiberglass filter unit) through which the gas sample flows enroute to the heated sample line. The particulate filter assembly, located in an electrically-heated cyclone oven (size - 9-1/2 inches square x 21-1/2 inches long), is maintained at 300°F. At normal operating conditions (no dust recycle), the particulate filter assembly had to be changed twice during each 24-hour operating period.

Freeboard Sample Locations

The mobile gas sampling system and probe installation shown in Figure 6 are used to traverse the freeboard at the locations previously shown in Figure 2. A typical traverse at one location would include taking gas samples at 12 or 13 points across the width of the facility. A complete traverse, conducted with the drive mechanism on either "hand mode" or "automatic mode", requires from 60 to 90 minutes to complete. Except for the difference in length, the furnace outlet and mobile probe-filter assemblies are identical.

In-Bed Sampling Locations

The in-bed gas sampling probe installation, shown in Figure 7, is used for traversing in the fluidized bed. The original in-bed probe-filter assembly is shown in Figure 8. The filters are 3/4 inches in diameter x 1-3/4 inches long with a pore size of approximately 1 micron. The ceramic collar is cemented to the filter at a position that is 1/4 inch away from the open end. The collar is clamped in the probe head at a location that presents an active filter flow area of approximately 2 square inches.

Typically, the ceramic filter had to be cleaned (nitrogen back-purged) at 15- to 20-minute intervals.

GAS SAMPLING PROBLEMS

The original gas sampling probes operated satisfactory and allowed accurate gas concentration measurements during no dust recycle test conditions. However, operation of the 6' x 6' AFBC unit has shifted to the use of dust recycle to improve performance. Dust loadings as high as 10,000 lb/hr have been run at temperatures up to 1750°F and at gas velocities of about 100 ft/sec. The high dust recycle increased the particulates that were entrained in the gas samples. This condition necessitated frequent filter changes, caused problems with glassware breakage due to increased handling, and required more frequent nitrogen back-purging of the in-bed filter.

Problems associated with gas sampling at the furnace outlet, freeboard, and in-bed locations are discussed in the following paragraphs.

Furnace Outlet Gas Sample Location

With high dust recycle rates, the filters required continual attention. Each filter change involved disconnecting and reconnecting five joints in the flow system. In a few instances, slight amounts of air infiltration (induced by negative pressure in the sample line) into the gas sample produced incorrect gas concentrations. Increased handling of the glassware and quartz tube produced some breakage problems. In certain instances, the breakage would occur as a crack that was difficult to detect. Undetected cracks, on a couple of occasions, permitted air infiltration into the sample in such a small quantity that the incorrect concentration readings went unnoticed for a few hours. These problems instigated a modified probe-filter assembly design that would provide more effective filtering. The modified design would eliminate the fragile components, such as glass and quartz, and would minimize the number of connection joints.

Freeboard Sample Locations

Problems with the probe-filter assembly were similar to those encountered at the furnace outlet location. Due to continual filter pluggage, the probe could not be used in the fringe area of the bed i.e., the lower sets of freeboard ports. Additionally, the long probe length (approximately 9 feet) and relocating the probe to all sample ports produced occasional breakage to the fragile components. Such actions also caused occasional air infiltration into the numerous connection joints.

In-Bed Sampling Locations

The solids density of the bed has always required the use of a nitrogen back-purge to clean the ceramic filter. A combination of the small active filter area (only 2 square inches) and the increased solids concentration increased the "blow-back-cleaning frequency". The resulting time required to conduct a traverse more than tripled that required for the no ash recycle test condition.

SOLUTIONS FOR SOLVING SAMPLING PROBLEMS

A review of sampling at all locations indicated that the components included in the probe-filter assemblies were responsible for the problems. Further review of the problems encountered at each location suggested that a modified probe-filter design could be adapted for sampling at all locations. The modified design actions included the following:

- Install a primary solids filter at the sample inlet to the probe. A ceramic filter, supplied by the Coors Porcelain Company, with an active filtering area of approximately 12 square inches was selected for this application. This filter (size - 1-1/4 inches OD x 3/4 inch ID x 4 inches long) with a pore size of 100 microns was included on the modified probe-filter assembly shown in Figure 9.

- Install a secondary filter between the sample probe and the heated sample line. A cartridge-type filter with two inches of kaowool insulation (also shown in Figure 9) was proposed to protect other components of the sample train in the case of a failure of the primary filter. This secondary filter would eliminate the glassware and plastic components which in turn would decrease the number of connection joints where possible air infiltration could occur. The insulation around the filter would eliminate the cyclone oven, controls, etc. thereby reducing the bulkiness of the installation.

- Remove the quartz tube (gas sample flow tube) from the center of the probe. This would eliminate another fragile component by allowing the sample to flow down the center (stainless steel tube) of the probe.

PERFORMANCE DATA SUPPORTS MODIFIED SYSTEMS

Primary Filter Performance

- The ceramic filter was initially tested at the furnace outlet gas sample location. At first, problems developed in sealing the ceramic filter and the metal tube. After obtaining a good seal, the ceramic filter performed to maximum expectations as shown by the following table:

Gas Temperature (°F)	Solid Flow Rate (lb/hr)	Gas Velocity (ft/sec)	Ceramic Filter Performance
800	3000	100	Sample system operated continuously for a period of 12 days (288 hours). Minimal wear to upstream side of filter.
800	10,000	100	Sample system required a filter change every 2 or 3 days. Minimal wear to upstream side of filter.

  The above tests were conducted without back-purging (with nitrogen) the filter. When the pressure drop across the filter reached its pre-determined maximum limit, the filter was changed.

- The filter tests in the freeboard area indicated that no pluggage occurred while sampling at any of the ports. No back-purge system was used and the filters showed no wear after extended periods of operation.

- The in-bed filter tests indicated that no pluggage occurred during a complete traverse across the bed. The original probe-filter assembly had to be back-purged with nitrogen every 15 or 20 minutes during each traverse. The nitrogen back-purge cleaning feature was available, but was not used during these latter tests. It appeared that the filters could be used indefinitely with no indications of wear.

Secondary Filter Performance

The secondary filter tests at the furnace gas outlet and freeboard sampling locations indicated the cartridge-type filter wrapped with two inches of kaowool insulation met all performance expectations. This filter served its initial purpose of protecting other components in the sample train in the case of a failure of the primary filter. It also replaced the fragile components and served to decrease the number of connection joints (possible air infiltration sources) in the sample train. The insulation contributed to the elimination of the cyclone oven which made the assembly less bulky and easier to handle. A combination of the insulated filter and controlled setting of the cooling water to the probe retained the gas temperature well above the dew point as the gas passed through the secondary filter enroute to the heated sample line. These tests were conducted in the most severe environment possible in both sampling locations. The secondary filter on the original in-bed probe-filter assembly was not changed, thus no secondary filter tests were conducted at this sampling location.

Quartz Tube Versus Stainless Steel Tube Performance Data

The original probe-filter assemblies used at the furnace gas outlet and freeboard sample locations contained a quartz tube through which the gas sample was drawn. Due to the fragile nature of the quartz, it was desirable to eliminate the quartz tube and instead use a stainless steel tube. Some concern existed that a gas-stainless steel reaction -- more likely at high gas temperatures -- could possibly produce incorrect gas concentrations (particularly with NO_x). By adjusting the water cooling rate on the probe, the temperature of the gas along its path of contact with the stainless steel was reduced to a low, non-reactive temperature level (200° to 400°F).

The results of the quartz tube versus stainless steel tube tests, conducted at the furnace gas outlet and freeboard sample locations, are shown in the following performance tabulation:

Sample Location	Sample Tube Diameter/Material (Inch)	Source Gas Temperature (°F)	Sample Gas Temperature In Probe (°F)	Gas Concentration Comparisons
Furnace Outlet	5/8 SS	800	300 Max	Gas concentrations for O_2, CO_2, CO, SO_2, and NO_x were essentially identical for both the quartz and stainless steel tube sample probes.
Furnace Outlet	5/8 Quartz	800	300 Max	
Freeboard	5/8 SS	1700	280 - 305	Gas concentrations for O_2, CO_2, CO, SO_2, and NO_x were essentially identical for the quartz tube and the two (5/8" and 3/8" diameter) stainless steel tube sample probes.
Freeboard	3/8 SS	1700	325 - 400	
Freeboard	5/8 Quartz	1700	155 - 220	

SUMMARY

Gas sampling and analysis form a major portion of the performance evaluation of the 6' x 6' AFBC facility. The analysis requires measuring the concentration of six different gases at three sample locations -- in-bed, freeboard, and furnace gas outlet. Sample flow rates of 6 to 10 liters per minute are needed for analyzing these gases.

Accurate sampling and analysis from the high-temperature - high velocity, dust-laden environment of the fluidized bed unit requires the use of a system that includes certain special equipment. An "efficient particulate filter" is needed to clean the large-volume gas samples removed from the adverse environment of the 6' x 6' unit. A ceramic filter -- constructed of inert material, self-cleaning, having minimum pressure drop, and able to withstand high temperatures and abrasive wear -- served as the primary particulate filter in our final design.

A cartridge-type secondary filter eliminated the glassware and decreased connection joints, while serving its main function of protecting the remaining sample system components in the case of a failure of the primary (ceramic) filter. Eliminating the quartz tube has produced a design that includes no fragile (glassware or quartz) components.

The modifications have been combined to produce a refined gas sampling system that can be used at sample locations of interest in fluidized beds. It has been used for collecting and for accurately analyzing gas data over extended test periods for a multiple number of planned test conditions. These results have played a major role in the evaluation of the AFBC performance. The refined gas sampling system -- developed for the 6' x 6' fluidized bed application -- is recommended as a reliable system for fluidized bed units.

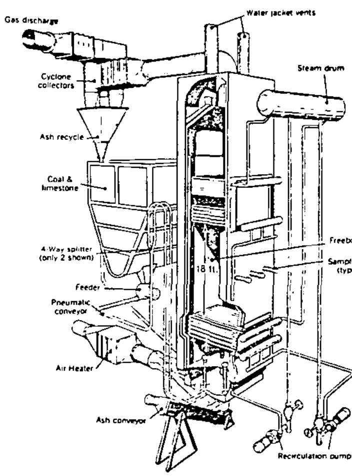

Figure 1 6' x 6' Fluidized Bed Combustion Facility

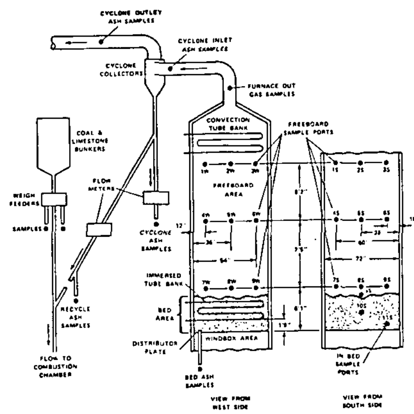

Figure 2 Relative Sample Locations for the 6' x 6' AFBC Facility

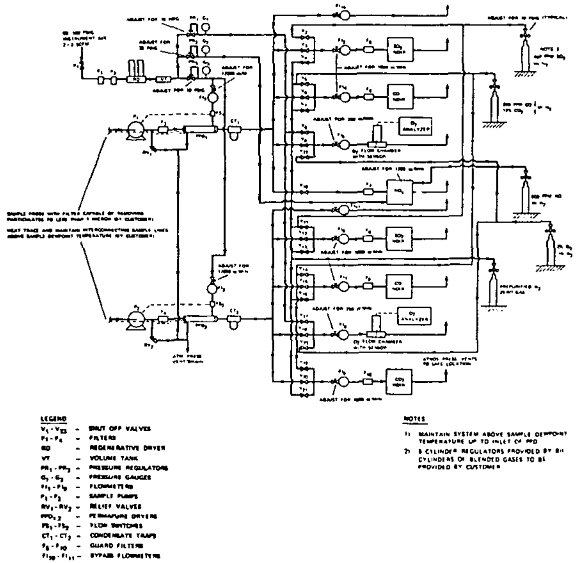

Figure 3 Complete 6' x 6' AFBC Facility Sampling System

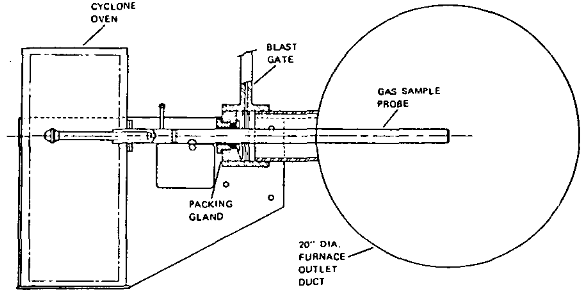

Figure 4 Furnace Outlet Gas Sampling Probe Installation

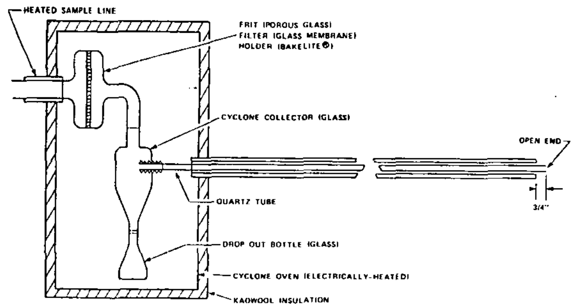

Figure 5 Original Furnace Outlet Gas Probe-Filter Assembly

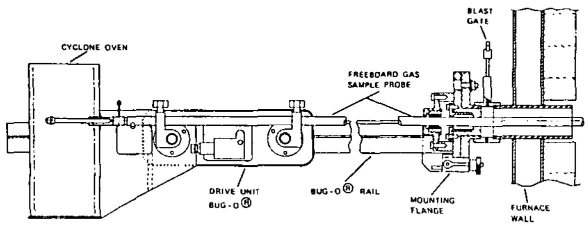

Figure 6 Freeboard Gas Sampling Probe Installation

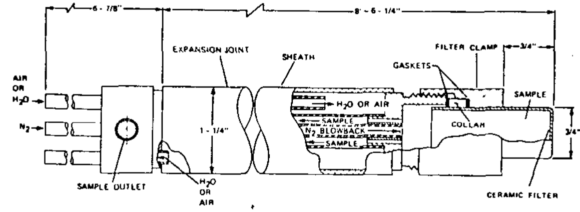

Figure 8 Original In-Bed Sampling Probe

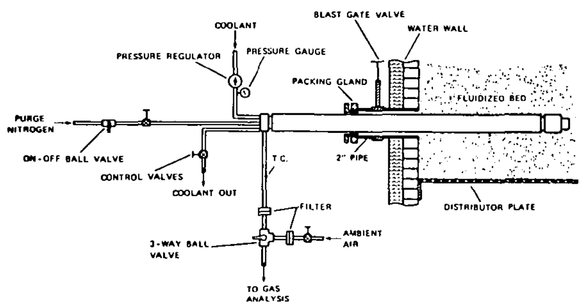

Figure 7 In-Bed Gas Sampling Probe Installation

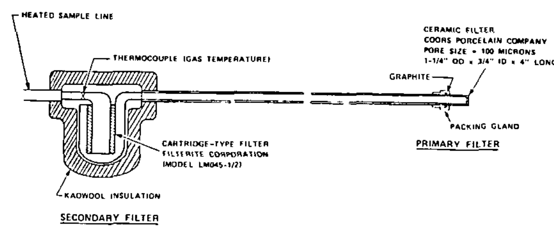

Figure 9 Modified Furnace Gas Outlet Probe-Filter Assembly